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The Multi-user Droplet Combustion Apparatus

Abstract

The Multi-user Droplet Combustion Apparatus (MDCA) is a multi-user facility designed to accommodate different droplet combustion science experiments. The MDCA will conduct experiments using the Combustion Integrated Rack (CIR) of the NASA Glenn Research Center's Fluids and Combustion Facility (FCF) on board the International Space Station (ISS). The FCF is a multi-user, microgravity science laboratory with three individually powered Space Station racks that accommodates both combustion and fluid type experiments. MDCA, in conjunction with CIR provided common hardware, will allow for cost effective extended access to the microgravity environment, not possible on previous space flights. Four droplet combustion experiments are currently identified to perform experiments in the MDCA. This paper provides and overview of the MDCA, including a description of it preliminary design and planned accommodation for microgravity droplet combustion science experiments.

Introduction

The Multi-user Droplet Combustion Apparatus Program supports research in how liquid-fuel-droplets ignite, spread, and extinguishes under microgravity conditions. Combustion, or burning, is a rapid, self-sustaining chemical reaction that releases a significant amount of heat. A major portion of the energy produced in the world today comes from the combustion or burning of liquid hydrocarbon fuels in the form of droplets. Improved understanding of the fundamental physical processes involved in droplet combustion will help us in more efficient ways of energy production and propulsion, as well as helping us deal better with the problems of combustion-generated pollution and fire hazards associated with liquid combustibles.

Despite vigorous scientific examination for over a century, researchers still lack a full understanding of many fundamental combustion processes. The ability to conduct more controlled experiments in space, without the complication of gravity, provides scientists with an opportunity to examine these complicated processes closely. The objectives of the NASA Glenn Research Center Mulit-user Droplet Combustion Program are to improve understanding of fundamental droplet phenomena affected by gravity, to use research results to advance droplet combustion science and technology on Earth, and to address issues of fire hazards associated with liquid combustibles on Earth and in Space.

Microgravity Droplet Combustion Science

The MDCA project at the NASA Glenn Research Center supports NASA's Microgravity Droplet Combustion Research Program. MDCA is a multi-user facility designed to accommodate different combustion science experiments. The modular approach permits the on-orbit replacement of droplet combustion Principal Investigator (PI) experiments such as different fuels, droplet dispensing needles, and droplet tethering mechanisms. Large components such as the avionics, diagnostics, and base-plate remain on-orbit to reduce up mass. MDCA is also designed to operate in concert with ground systems on Earth to minimize on-orbit crew involvement.

Four Principal Investigators are currently planning to use the MDCA to study the combustion of small, spherical droplets of pure and bi-component fuels. Isolated liquid fuel droplets remain the easiest to study because of their well defined system. Three of the investigators will study the combustion of single droplets in a quiescent environment. The Droplet Combustion Experiment (DCE-2) reflight investigation will further explore droplet combustion behaviors, especially related to extinction phenomena. These were first observed during its first flight on the Microgravity Science Laboratory -1 (MSL-1) flight in the SpaceLab Module onboard Space Shuttle Flights STS-83 and 94 in April and July 1997. The Bi-Component Droplet Combustion Experiment (BCDCE) has its focus on the internal liquid fluid dynamics and combustion of bi-component fuel droplets. This experiment will be the first to study how each fuel species and their capillary forces drive the internal flow dynamics and combustion of a burning droplet. Sooting behaviors of droplets are the focus of the Sooting Effects in Droplet Combustion (SEDC) Investigation. The goal of this experiment is to measure and sample soot generated from a burning droplet. An understanding of the formation of soot and how it travels is important in fire safety. In contrast to the first three droplet investigations in a quiescent environment, the Dynamic Droplet Combustion Experiment (DDCE) plans to investigate the effects of small convective flows on the droplet during combustion such as may be found in the ventilation systems of space vehicles. This will improve the understanding of enhanced fire safety margins in spacecraft.

The MDCA is being developed by the Analex Corporation (Cleveland, Ohio) under the Federal Data Corporation contract to NASA Glenn Research Center.

The MDCA is shown in Figure 1.0.

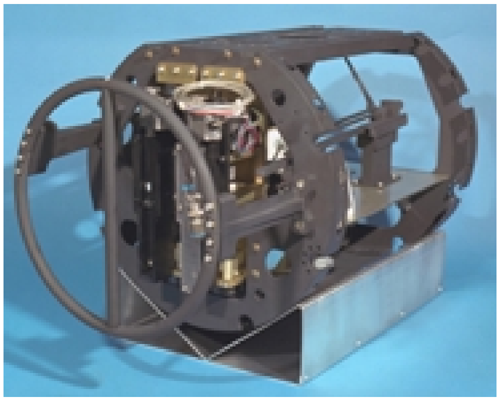

Figure 1.0 Multi-user Droplet Combustion Apparatus

The Carrier

The Combustion Integrated Rack (CIR) will support the MDCA by providing the structural support for the MDCA Chamber Insert Assembly (CIA), the MDCA Avionics Package, and PI unique diagnostics. The CIR will also provide the utilities for the avionics and diagnostics packages, and the mixing capability for PI specific combustion chamber environments. Common diagnostics provided by the CIR will also be utilized by the MDCA.

The CIR also allows for different combustion chamber environments by means of the Fluids Combustion Facility Fuel/Oxidizer Management Assembly (FOMA) system. The reorientation and interchangeability of hardware systems to meet PI specific needs will be controlled by both and CIR. The CIR with the MDCA is shown in Figure 2.0.

Figure 2.0 MDCA with CIR

Multi-user Droplet Combustion Apparatus

The Multi-user Droplet Combustion Apparatus (MDCA) is a multi-user platform used for conducting droplet combustion experiments onboard the International Space Station (ISS). The apparatus will utilize the Combustion Integrated Rack (CIR), which is apart of the Fluids and Combustion Facility (FCF). It has been designed to allow for the investigation of different size fuel droplets that are freely deployed or fuel droplets requiring support by a tether. A multitude of imaging diagnostics allows for droplet viewing, flame viewing, and color viewing. Principal Investigator unique measurement capability is also provided and includes radiometric, soot volume faction, soot pyrometry, soot sampling, and particle imaging measurements.

The four initial MDCA experiments include:

- Droplet Combustion Experiment-2 (DCE-2)
- Bi-Component Droplet Combustion Experiment (BCDCE)
- Sooting and Radiation Effects of Droplet Combustion (SEDC)
- Dynamics of Droplet Combustion and Extinction (DDCE)

The MDCA hardware consists of the Chamber Insert Assembly (CIA), an Avionics Package, and a multiple array of diagnostics. The MDCA CIA offers the interchangeability of the fuel system, igniter system, droplet dispensing system, and droplet tethering system.

MDCA Subsystems

Chamber Insert Assembly

The MDCA CIA provides all necessary hardware and interfaces to perform PI science on one platform. Most experimental functions occur within the CIA structure. The CIA consists of two major components: an Experimental Mounting Structure (EMS) and an Internal Apparatus (IA). The EMS provides the main structure for the CIA and acts as the primary mechanical interface with the CIR combustion chamber. It consists of two endplates, support structure and removable shrouds to protect the IA during crew activity. The IA provides the primary mounting platform for all experiment specific hardware and functions to include droplet dispensing, deployment, and ignition. The IA encompasses all motors used for the operation of the experiment, a water-cooled system, radiometers, and an internally mounted color camera. The IA also provides for future add-on hardware for follow-on

PI’s. The Chamber Insert Assembly is shown in Figure 3.1.

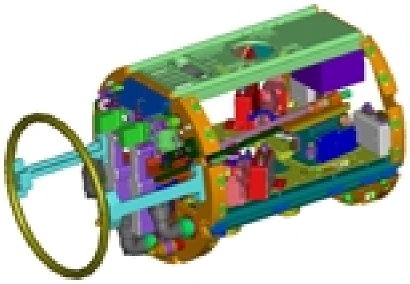

Figure 3.1 Chamber Insert Assembly

Other subsystems on the CIA include the Droplet Dispensing System, Droplet Deployment System, Fiber Support System and Ignition System. There are two independent replaceable dispenser systems on the IA. Each system consists of a motor housing, replaceable fuel reservoir filled with the PI specific fuel, and fuel isolation valve. Flexible tubing connects the fuel system to the deployment needles. Fuel is dispensed by means of a lead screw on the motor, which in turn pushes the plunger on the syringe. The Dispensing System is shown in Figure 4.1.

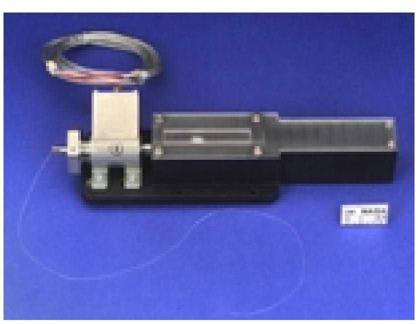

Figure 4.1 MDCA Dispensing System

The Droplet Deployment System consists of two independent replaceable deployment needles made of 0.010 inch outer diameter stainless steel tubing supported by a ceramic sleeve. Each needle is bent 90 and flared at the end to aid in droplet deployment. The needles are mounted to individual rotary servomotors that rotate the needles to a predetermined location, creating a minimal gap between the tips. Fuel is metered to the end of the needle tip forming a droplet of precise volume. The droplet then centers itself between the two needles. The needles are rapidly accelerated apart, deploying the droplet off the needle tips. The rapid acceleration leaves the droplet in place with minimal to no residual motion. See Figure 5.1 for a pictorial depiction of the Droplet Deployment System.

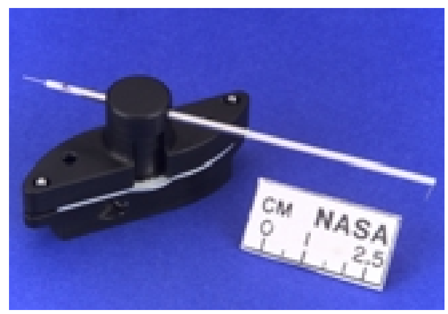

Figure 5.1 Droplet Deployment System

The Fiber Support System consists of a replaceable Retractable Indexing Fiber (RIF) mechanism, 229 mm long, supporting a 79micron diameter silicon carbonitride fiber fastened between two support arms with epoxy to a tension of 3000 psi. The RIF assembly allows for the fuel droplet to be deployed onto, and thus tethered to, the fiber during experimental burn and observation. When used, the fiber is rotated 200 deg into the deployment area by means of a rotary stepper gear motor. The RIF also translates along its axis, to provide a clean portion of the fiber for successive experimental tests. See Figure 6.1.

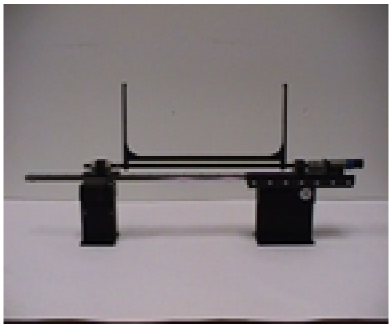

Figure 6.1 Retractable Indexing Fiber

The Ignition System consists of two independent replaceable hot wire igniters opposed 180 deg, controlled by individual actuators. The ignition wires are 4mm diameter loops of Kanthal A-1 wire, 30 AWG (American Wire Gauge). Each loop is mounted to a ceramic structure. The assembly is fully replaceable. The ceramic igniter sleeve has two pins that mate with two sockets on the igniter-mounting interface. This interface is fixed to the igniter motors. These motors move the igniters into the deployment area in precise linear steps and then quickly retract the igniters after ignition. The Ignition System is shown in Figure 7.1.

Figure 7.1 MDCA Ignition System

Avionics

The Avionics Package provides the processing and control interface hardware for controlling the MDCA and communicating with the CIR hardware.

The avionics controls the CIA motors, provides the functions for input and output data control, and is the source for experimental data collection. The package will receive electrical power at 28 VDC from the CIR. DC-DC converters within the avionics will convert the voltage necessary for MDCA operation. The package will acquire health and status data from the CIA via dedicated input/output lines. The data will be downloaded to the CIR Input/Output Processor (IOP) via the CIR Ethernet for downlink. MDCA commands will be uplinked from the ground to the IOP, or issued from a Station Support Computer (SSC) to the IOP. The IOP will transmit the commands to the avionics package via the CIR Ethernet. The enclosure of the avionics package will provide the Electromagnetic Interference (EMI) shielding and provide the grounding to the CIR optics bench. See Figure 8.1.

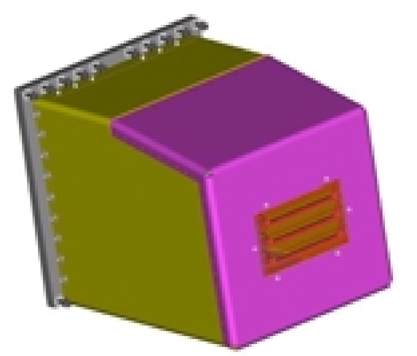

Figure 8.1 MDCA Avionics Enclosure

Diagnostics

The majority of diagnostic hardware will be CIR provided with some elements provided by MDCA. The diagnostics hardware selection and configuration is specific to each experiment: DCE-2, BCDCE, SEDC, and DDCE. The diagnostics are modular and can be replaced on orbit.

Individual components making up each diagnostics can also be replaced or changed (such as filters, lens, etc.)

The diagnostics hardware is mounted on the CIR optics bench that provides the structural support, electrical connections, and thermal control. The optics bench has eight (8) designated Universal Mounting Locations (UML) arranged around the outside of the CIR combustion chamber and aligned to permit the diagnostic hardware to view the interior of the chamber and the MDCA CIA through optical windows. Standard avionics air-cooling, electrical power and data interfaces are provided at each UML.

CIR provided diagnostics hardware for MDCA includes:

- High Bit Depth/Multi-Spectral Imaging Package (HiBM) – measures soot volume fraction and soot temperature of soot-producing flames.
- High Frame Rate/High Resolution Camera (HFR/HR) – a camera capable of 110 frames per second having a telecentric imaging system.
- Low Light Level Packages (UV and IR) – provides images of events or objects at low radiance levels (~6x10 "-6" ft-candle minimum illumination) in the Ultraviolet and IR range.
- Illumination Package – provides an illumination source to the chamber and is used in conjunction with Diagnostics packages that require backlight illumination.

MDCA provided diagnostics hardware includes:

- Color Camera – mounted on the CIA providing enhanced color imaging of combustion experiments.
- Radiometers – mounted on the CIA providing measurement of radiation during combustion.
- Illumination/Particle Imaging Velocimetry Package – mounted on the CIR optics bench providing measurements of the droplet's internal flow velocities.

MDCA Operations

The MDCA is designed to conserve up-mass, crew-time, and combustion resources while maximizing flexibility for the crew and the experiment. Once configured on-orbit, the operations staff at the GRC Telescience Support Center (TSC) will operate the experiment remotely. Data is transmitted to experimenter's at their home sites allowing direct interaction with the PI and operations staff to maximum science.

MDCA Design Approach and Status

The MDCA development approach is to design, fabricate, and test the following:

1. A Functional Model that will be upgraded to a high fidelity mockup for crew evaluation and training.
2. An Engineering Model that will eventually be used as a Ground Integration Unit, configured the same as the unit on-board the ISS, for checkout of specific experimenter hardware and software.
3. A Protoflight unit that will be flown in the FCF on ISS.

Summary

The MDCA is being developed with modular cost effective design that allows for maximum flexibility

The FCF onboard ISS will provide the long-term microgravity environment that has never been available to experimenters in the past. The ISS era will truly allow for the maximum return of combustion science and technology for them minimum investment of resources.

Acknowledgements

The MDCA is being developed by the Analex Corporation (Cleveland, Ohio) under the Federal Data Corporation Contact monitored by the Combustion Flight Projects Branch of the Microgravity Science Division (MSD) at the NASA Glenn Research Center.

References

Francisco, David R., “Fluids and Combustion Facility Combustion Integrated Rack, AIAA 98-0257, 36th Aerospace Sciences Meeting & Exhibit, Reno NV, 1998